ANALISIS TOMOGRAFI 3D PADA GEMPA BUMI DI SUMATERA MENGGUNAKAN *LOCAL EARTHQUAKE TOMOGRAPHY*

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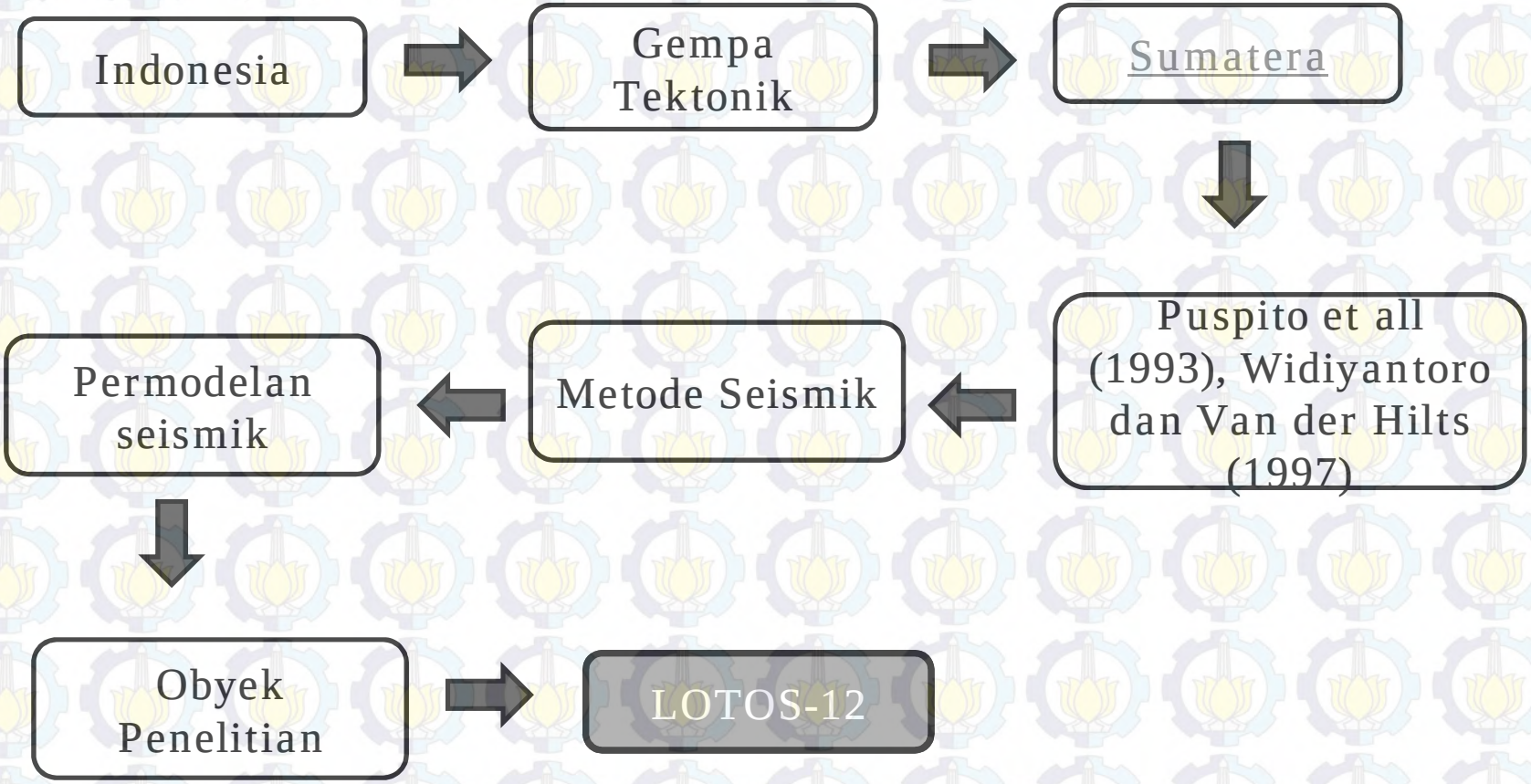
Program Pascasarjana
Jurusan Fisika
Institut Teknologi Sepuluh Nopember
2015

Pendahuluan



Pendahuluan

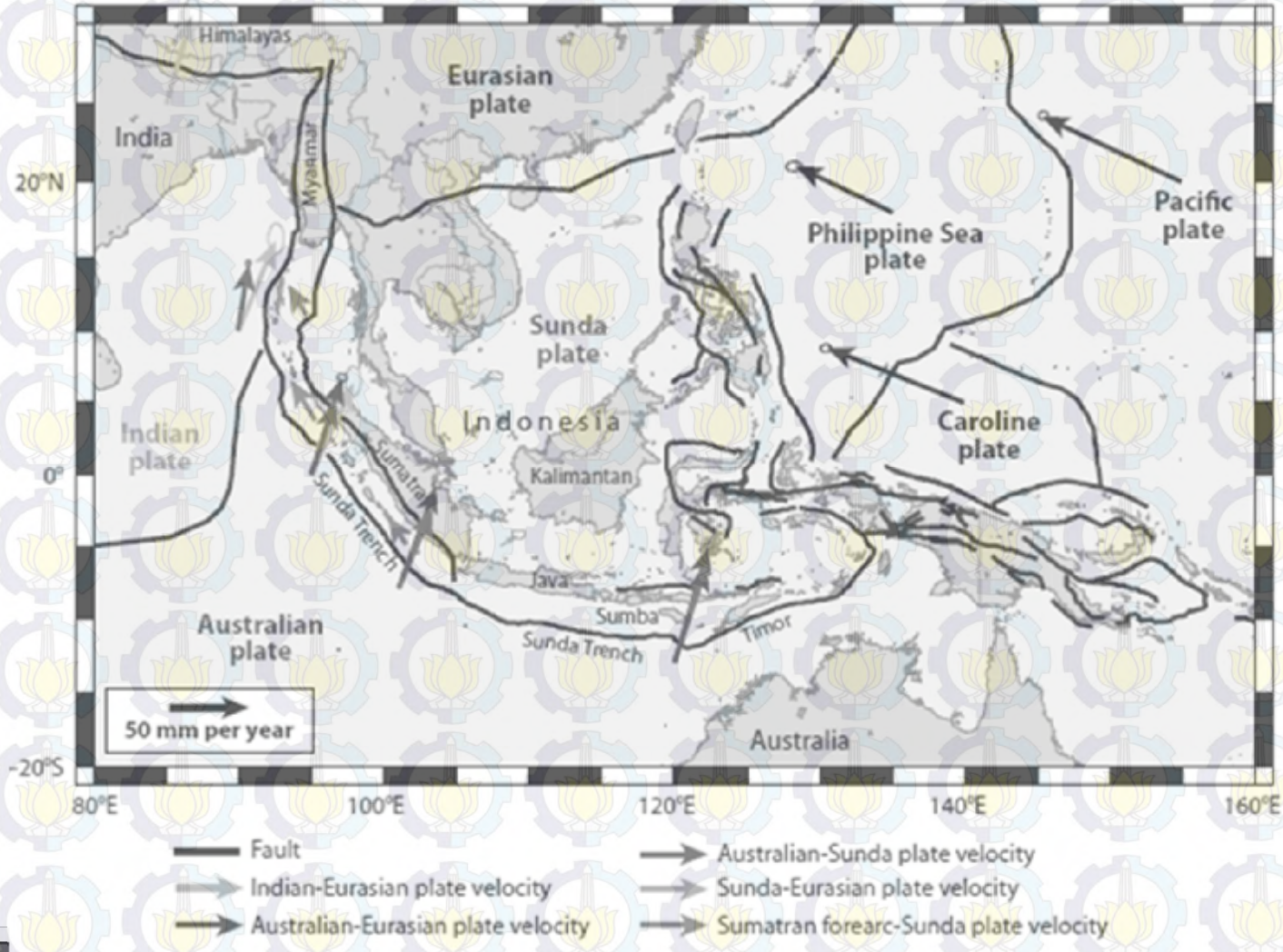
Rumusan Masalah dan Tujuan

- Waktu tiba gelombang-P (tp) dan waktu tiba gelombang-S (ts).
- Distribusi anomali kecepatan gelombang-P dan kecepatan gelombang-S.
- Tomografi 3D Pulau Sumatra menggunakan LOTOS-12.

Batasan Masalah

- Data yang digunakan merupakan data gempa bumi di pulau Sumatera (6^oLU-6^oLU dan 95^oBT-108^oBT) pada tanggal 10 Maret 2013 sampai 10 Maret 2014.
- Pengolahan data awal pada penentuan waktu tiba gelombang-P dan waktu tiba gelombang-S menggunakan Seisgram2K60 *Software*.
- Proses inversi tomografi menggunakan LOTOS-12

Struktur Geologi Sumatera

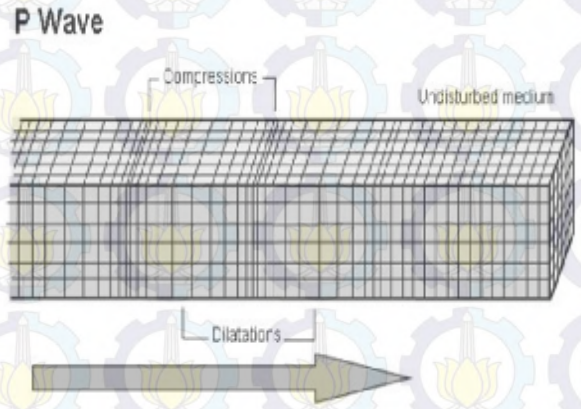


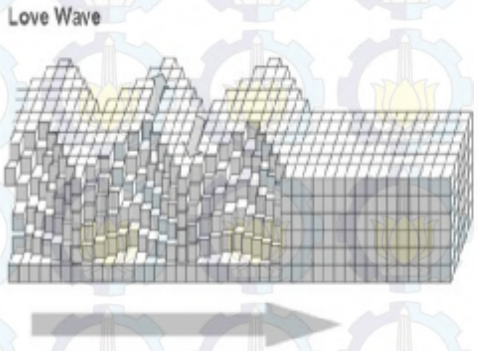
Kajian Pustaka

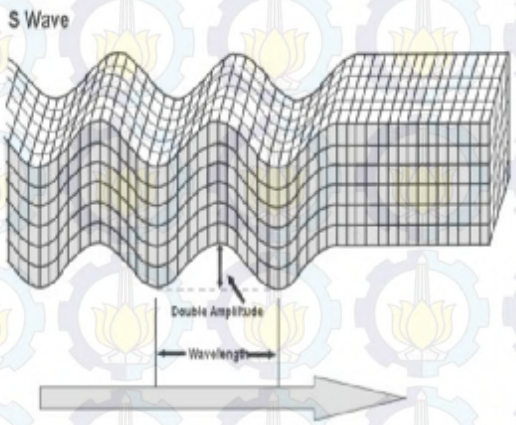
Gelombang Seismik

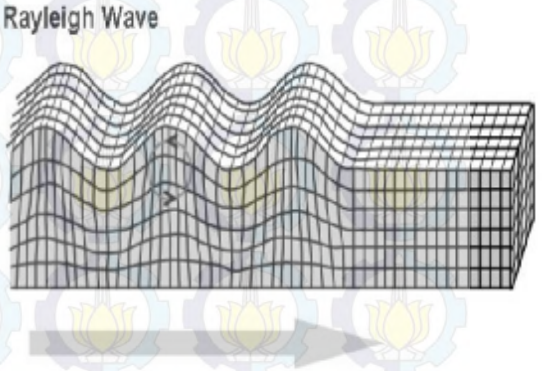
Gelombang Badan
- Gelombang Primer
- Gelombang Sekunder

Gelombang Permukaan
- Gelombang *Rayleigh*
- Gelombang *Love*









Kajian Pustaka

Penentuan Hyposenter dengan Hypo71

Hiposenter: lokasi gempa (data lattitude, data *longitude* dan data kedalaman bawah permukaan serta data waktu asal).

Ø Hypo71 : *file* .INP , *file*. PRT dan *file* .PUN

- Persamaan residual : $r_e = t - t_0 - t^{cal}$
- Persamaan kuadrat terkecil :
- Linierisasi persamaan kuadrat $F(x)_{kecil} = \sum_{e=1}^{M} r_e^2$
- Matriks persamaan residual: $J\Delta m = \Delta d$ $r_e = \frac{\partial T_e}{\partial X_0} dx + \frac{\partial T_e}{\partial Y_0} dy + \frac{\partial T_e}{\partial Z_0} dz + dt$

(J: matriks Jacobian, Δm: hiposenter yang ingin diperbaiki Δd: parameter data)

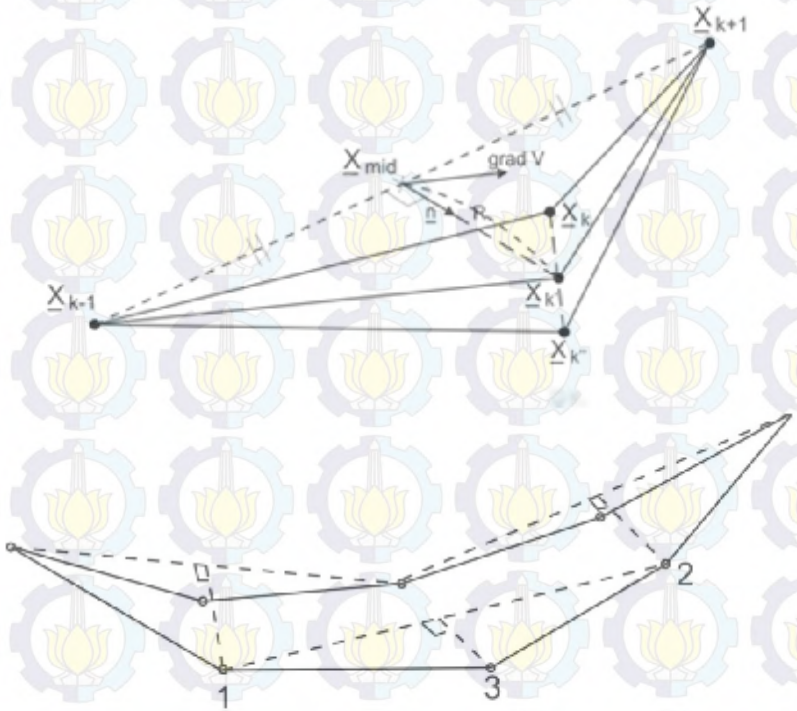
- Hiposenter yang ingin diperbaiki

$$[J]^T[J]\Delta m = [J]^T \Delta d$$

$$\Delta m = [J^T J]^{-1} J^T \Delta d$$

Inversi Tomografi LOTOS-12

Ray Tracing

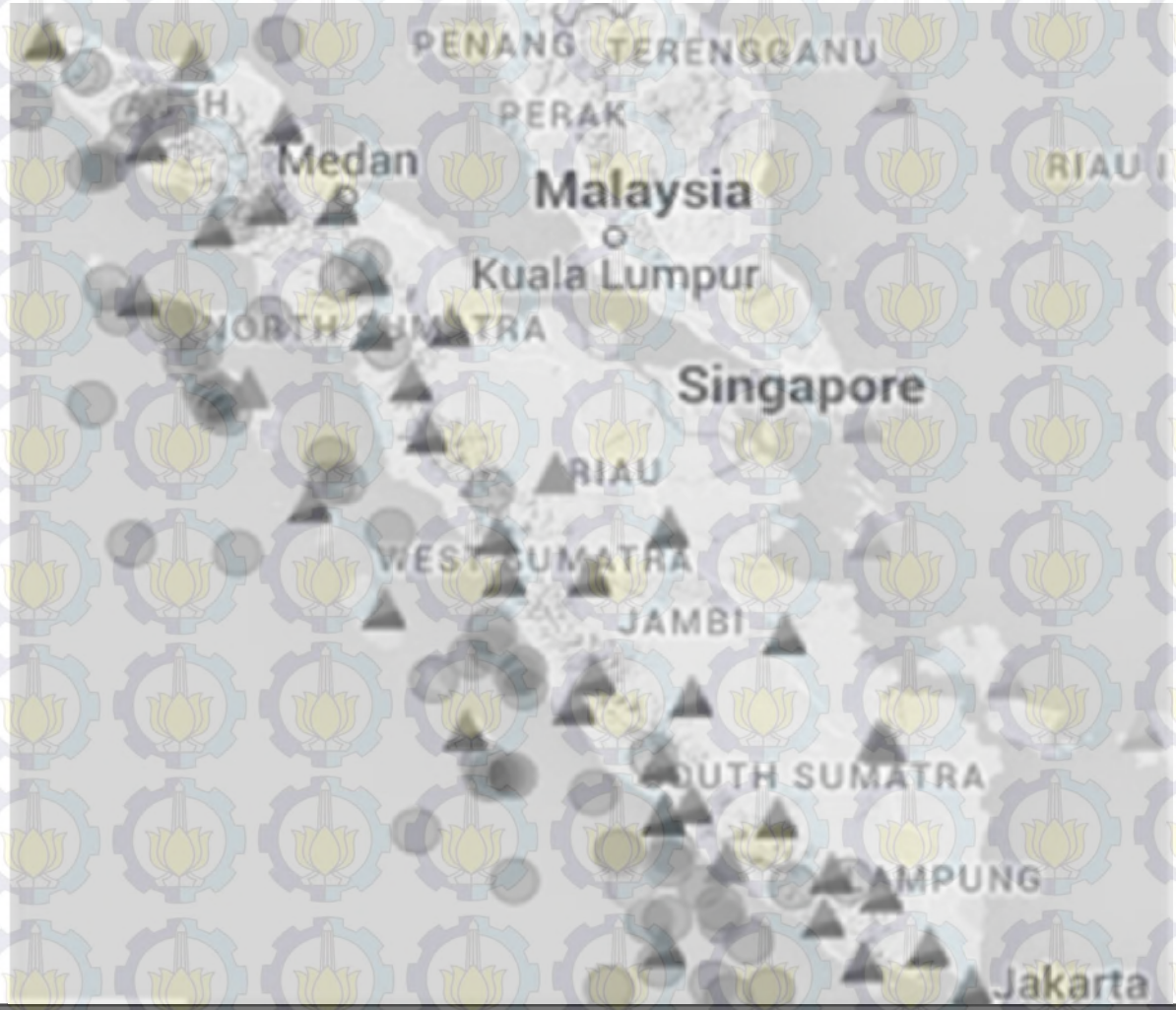


Kelebihan :

- Selain inversi untuk Vp dan Vs, LOTOS-12 juga memiliki kemampuan untuk menginversi Vp/Vs
- Disediakan beberapa contoh berbeda yang dapat digunakan untuk merekonstruksi model baru
- Hasil dalam bidang horisontal dapat disajikan dalam tipe PNG *bitmap* tanpa menggunakan *software* grafis apapun

Metodologi

Area Penelitian



Metodologi

Data Penelitian

Data didownload dari
www.WebDc.eu

Batas Wilayah :
6°LU - 6°LU dan 95°BT - 108°BT

Rentang waktu :
10 Maret 2013 - 10 Maret 2014

Magnitude : ≥ 4,7 SR

Stasiun perekam : 35 Stasiun

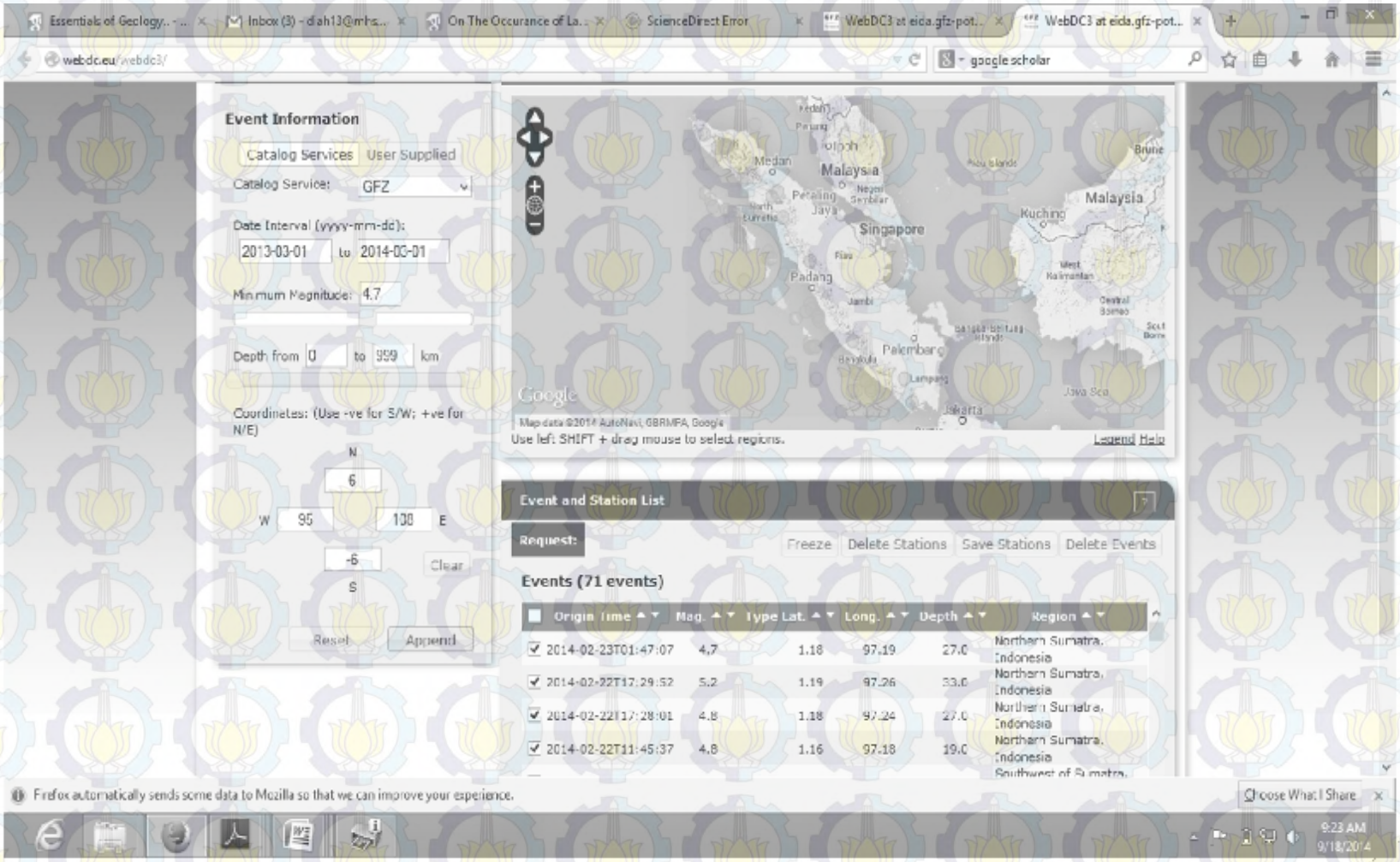
71 *event*
2.482 gelombang seismik

Metodologi

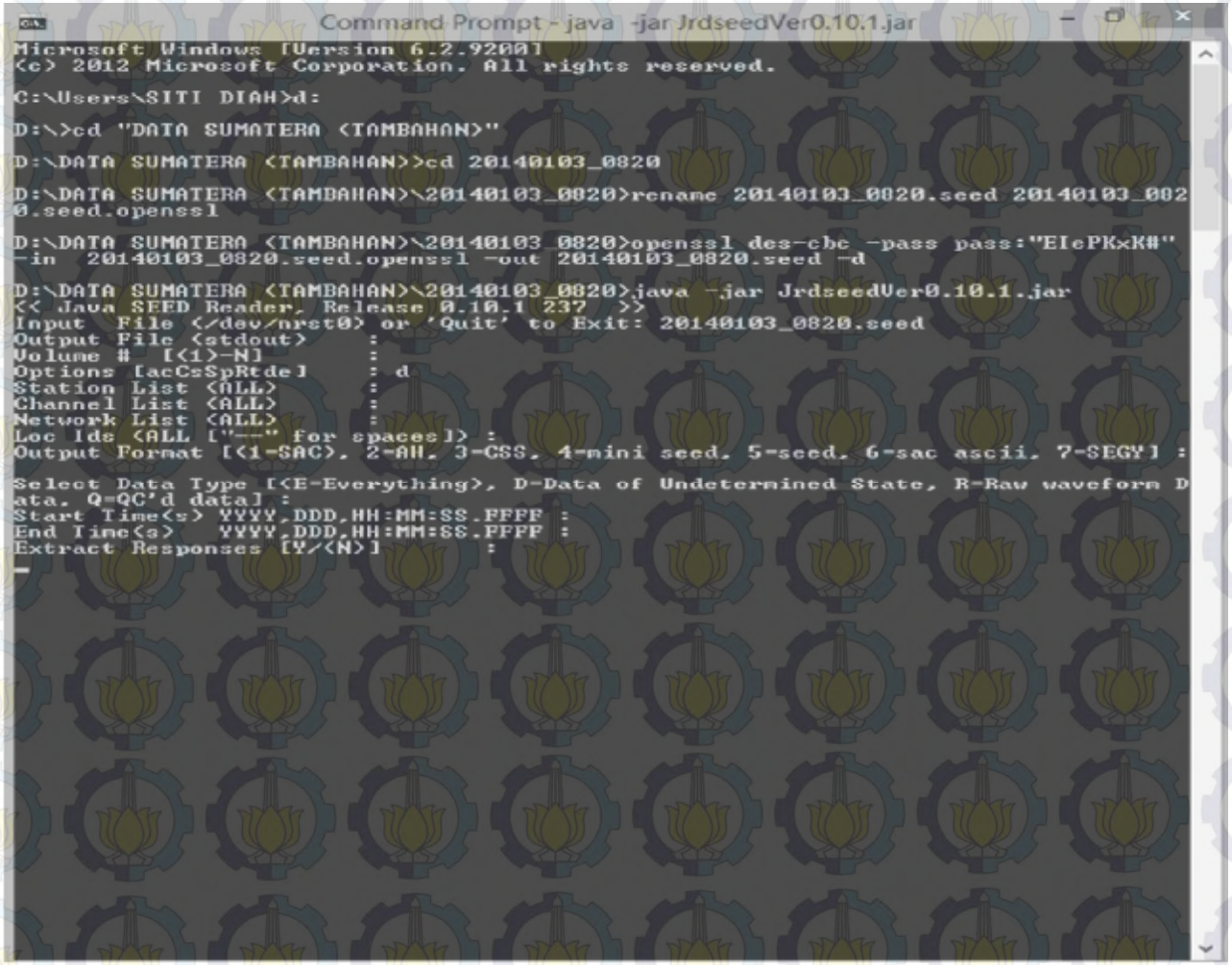
Alat

- Openssl-0.9.8k_win64
- Jrdseed
- TauP-2.1.1
- Seisgram2k60
- Hypo71
- ArcViewGis3.3
- LOTOS-12

Download data di katalog gempa www.webDc.eu



Openssl (meng-*encript* data dari WebDC)
Jrdseed (mengubah format *seed - banyak *file* *SAC)



TauP-2.1.1 (Perkiraan Tp dan Ts)

The TauP Toolkit

Time | Pierce | Path

Dist	Dist (km)	Depth	Name	Time	Ray Par...	Purist Di...	
0.42	46.99	18.0	p	8.67	17.871	0.42	=
0.42	46.99	18.0	P	8.93	17.053	0.42	=
0.42	46.99	18.0	P	8.93	17.327	0.42	=
0.42	46.99	18.0	s	14.96	30.853	0.42	=
0.42	46.99	18.0	S	15.42	29.559	0.42	=
0.42	46.99	18.0	S	15.42	29.910	0.42	=
0.42	46.99	18.0	PcP	508.18	0.041	0.42	=
0.42	46.99	18.0	ScS	930.22	0.075	0.42	=
0.42	46.99	18.0	PKiKP	991.47	0.009	0.42	=
0.42	46.99	18.0	SKiKS	1413.51	0.011	0.42	=

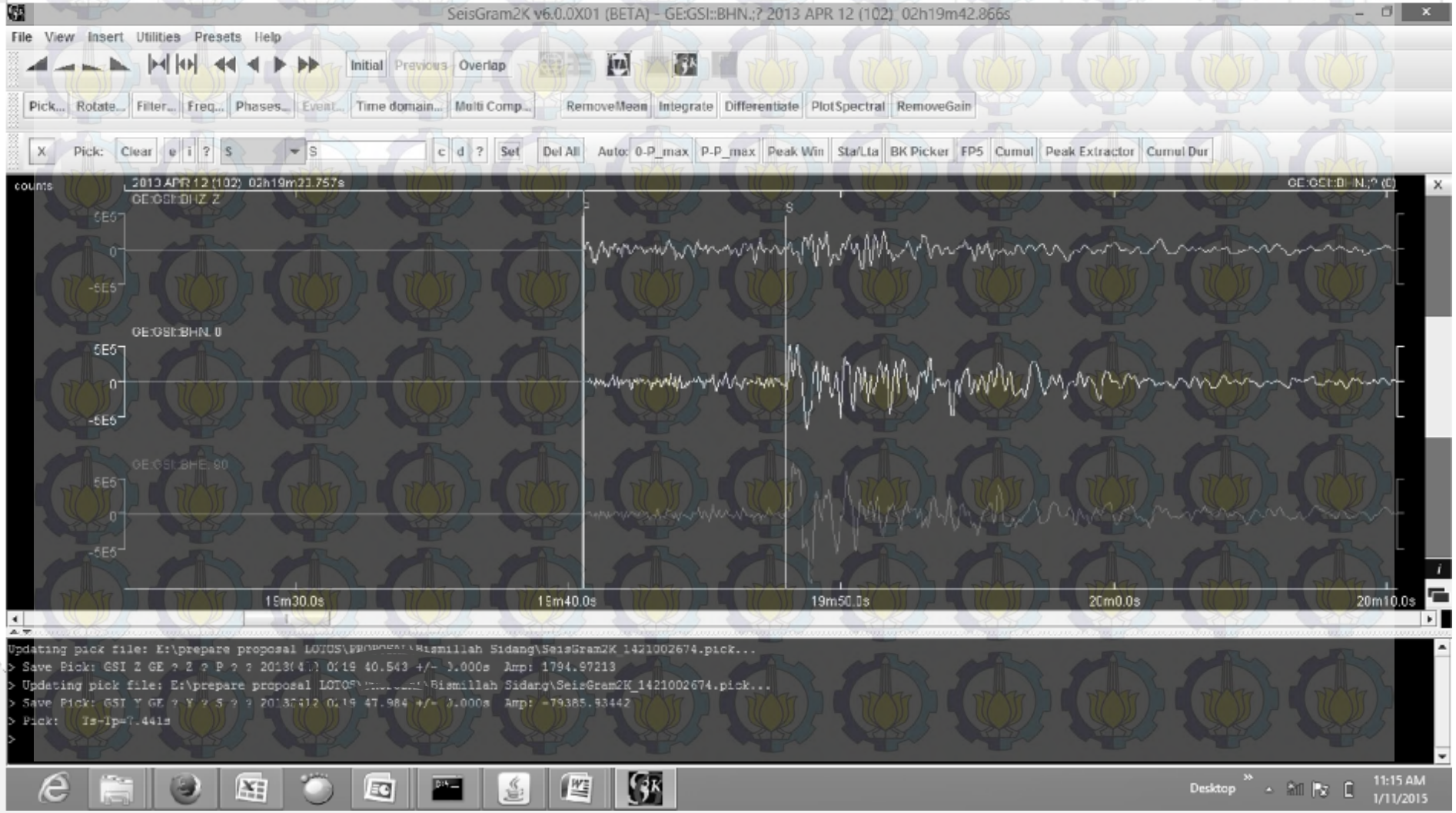
Model iasp91 | Distance (deg) 0.4226 | Calculate

Phases | Depth 18 | Quit

Prosedur

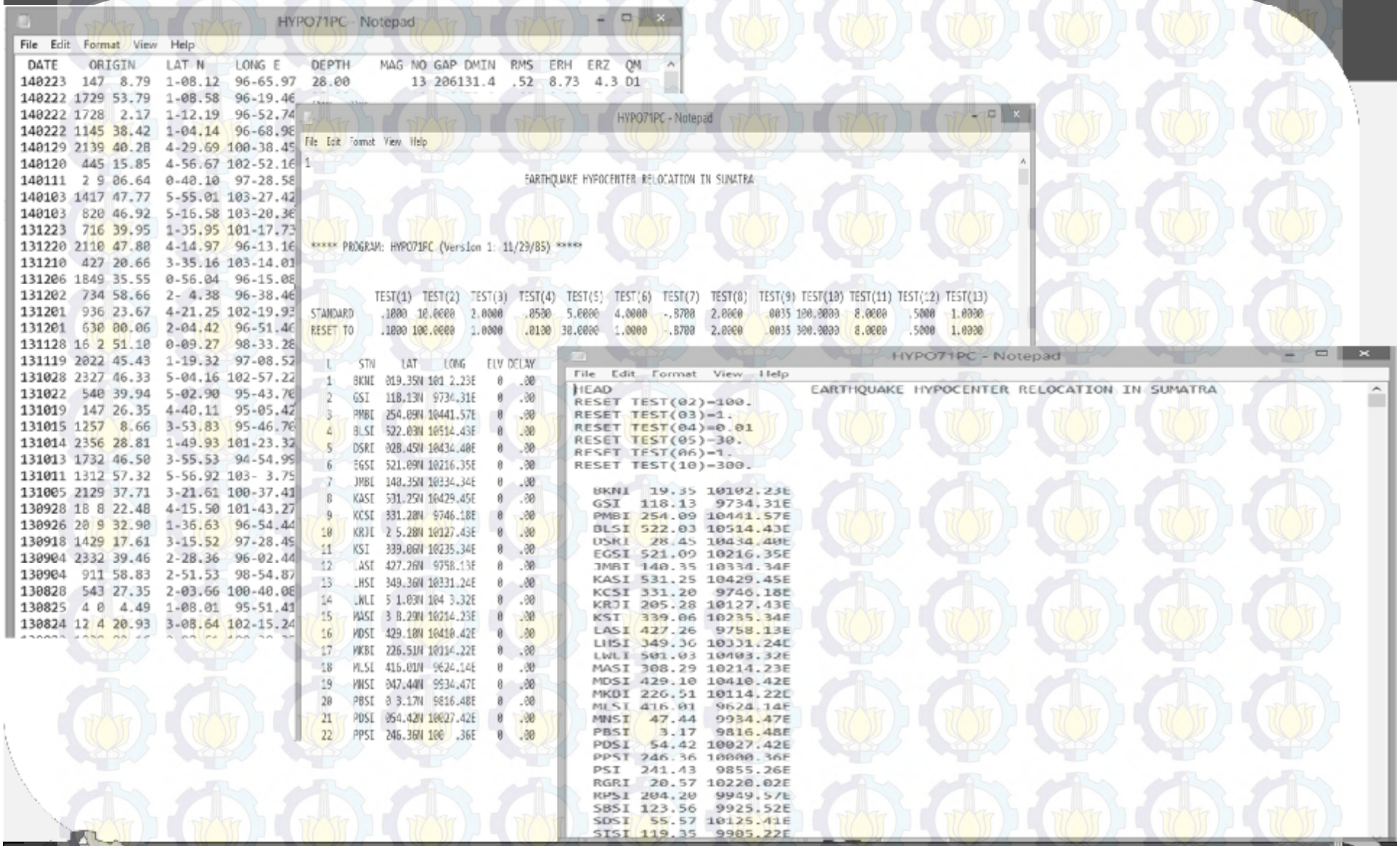
Picking Gelombang Seismik

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Event	Stasiun	Origin	P (fix seis)	S (fix seis)	P (from taup)	S (from taup)	P-O (fromtaup)	S-O (from taup)	O.HYPO	O	P	S	P-O	S-O
2	64	GSI	2:19:30	02:19:40:543	02:19:47:984	02:19:38.93	02:19:45.42	12:00:09 AM	12:00:15 AM	02:19:30.54	1170.54	1180.543	1187.984	10.003	17.444



Relokasi Hyposenter Hypo71

Prosedur



Prosedur

rays - Notepad

File Edit Format View Help

```
 97.11000      1.14000     28.00              25
        1           20  25.535
        2           20  45.333
        1           30  23.419
        2           30  42.667
        1            9  35.164
        2            9  64.683
        1           33  29.965
        2           33  63.095
        1           23  34.744
        2           23  61.319
        1           28  46.366
        2           28  83.430
        1           18  47.160
        2           18  83.654
        1           12  49.609
        2           12  89.064
        1           21  57.076
        2           21  99.076
        1            1  53.192
        2            1  102.68
        1           22  65.563
        2           22  126.22
        1           10  74.724
        2           10  140.27
        1           17  75.797
 97.11000      1.15000     35.20              36
        1           30  30.278
        2           30  49.364
        1           23  32.713
        2           23  59.980
```

stat_ft - Notepad

File Edit Format View Help

```
 101.03964     0.3254167     1.000000   BKNI
 97.575400      1.303600     1.000000   GSI
 104.69925     -2.902430     1.000000   PMBI
 105.24521     -5.367548     1.000000   BLSI
 104.58000    -0.4793000     1.000000   DSRI
 102.27629     -5.352410     1.000000   EGSI
 103.57600     -1.676400     1.000000   JMBI
 104.49596     -5.523610     1.000000   KASI
 97.771570      3.522185     1.000000   KCSI
 101.46193     -2.091199     1.000000   KRJI
 102.59290     -3.651700     1.000000   KSI
 97.970370      4.457251     1.000000   LASI
 103.52333     -3.826624     1.000000   LHSI
 104.05891     -5.017472     1.000000   LWSI
 102.23961     -3.141521     1.000000   MASI
 104.17823     -4.486037     1.000000   MDSI
 101.23958     -2.447400     1.000000   MKBI
 96.403980      4.256851     1.000000   MLSI
 99.579630     0.7954980     1.000000   MNSI
 98.280000    -0.0547000     1.000000   PBSI
 100.46170    -0.9118000     1.000000   PDSI
 100.01000     -2.776600     1.000000   PPSI
 98.924000      2.695200     1.000000   PSI
 102.33380    -0.3491000     1.000000   RGRI
 99.832500      2.072300     1.000000   RPSI
 99.431000      1.398800     1.000000   SBSI
 101.42300    -0.9325000     1.000000   SDSI
 99.089500     -1.326500     1.000000   SISI
 102.59270     -2.392400     1.000000   SLSI
 96.326700      2.438900     1.000000   SNSI
```

MAJOR_PARAM - Notepad

File Edit Format View Help

```
**************************************************
GENERAL INFORMATION :
1       KEY 1: REAL; KEY 2: SYNTHETIC
1       KEY 1: Vp and Vs; KEY 2: Vp and Vp/Vs
0       KEY 0: all data, KEY 1: odd events, KEY 2: even events
1       Ref. model optimization (0-no; 1-yes)
1       1: geogr, 2: Cartesian
0       1: true locations exist in separate line
2       1: calculations in a flat model, 2: spherical velocity


**************************************************
AREA_CENTER :
100.9919 -0.7289813    Center of conversion to XY


**************************************************
1D LOCATION KEY :
1    1: using reference table (large areas);
     2: using straight lines (small areas with high relief)


**************************************************
```

Inversi Tomografi LOTOS-12

Prosedur

ref_start - Notepad

File Edit Format View Help

		Ratio vp/vs
0.000	2.31	1.3
1.000	4.27	2.4
2.000	5.52	3.1
5.000	6.23	3.5
16.000	6.41	3.6
33.000	6.70	4.4
40.000	7.80	4.46
100.000	8.00	4.57
225.000	8.40	4.8

config - Notepad

File Edit Format View Help

```
******* MAP VIEW *********
500 800                 size in pixels for horizontal section
1 1                     ticks on axes for horizontal sections
******* VERTICAL SECTION *********
500 600                 size in pixels for vertical section
25 35                   ticks on axes for vertical sections
******* PLOTS WITH 1D VELOCITIES *********
500 800                 size in pixels for the 1D models
2 10                          Limits of P and S velocity distribution
-175 0                  Depth limit
0.5 25                  ticks on axes for 1D velocity plot
******* SCALES *********
blue_red.scl    scale for velocity anomalies
-10 10                  diapason for velocity anomalies, %
blue_brown.scl  scale for Vp/Vs
1.4 1.99                        diapason for Vp/Vs
rainbow_small.scl       scale for absolute Vp
3.0 8.5                 diapason for absolute Vp
rainbow_small.scl       scale for absolute Vp
1.5 5.5
```

sethor - Notepad

File Edit Format View Help

```
10                      Number of sections
10 20 40 60 80 100 120 140 180 200      Depths of sections
-3 3 0.1 -4.0 4.0 0.1 fi1, fi2, dfi, tet1, tet2, dtet
10          distance from nearest node
0               Smoothing factor1           Number of summary
0               index for source visualization
```

setver - Notepad

File Edit Format View Help

```
3               Number of different sections
100.55512000,  1.1446200
101.82175000, -6.7515800
99.369350000,-0.17591000
103.95076000, -6.0508900
101.76785000,-0.01421000
99.531040000, -5.1615600
10    distance from section for visualization of events
3                       dx
0 180 3         zmin,zmax,dz
50               Marks for indication of position of section
8               Distance to the nearest node
0               Smoothing factor
1               If 0, no sources are visualized
2 1             horizontal section and PS to show the location of profiles
0.10 0.10       dfi, dtet: shift fo
```

Diagram Alir Penelitian

Studi Pustaka

Pengumpulan Data

Picking Data Seismogram

Relokasi Hiposenter

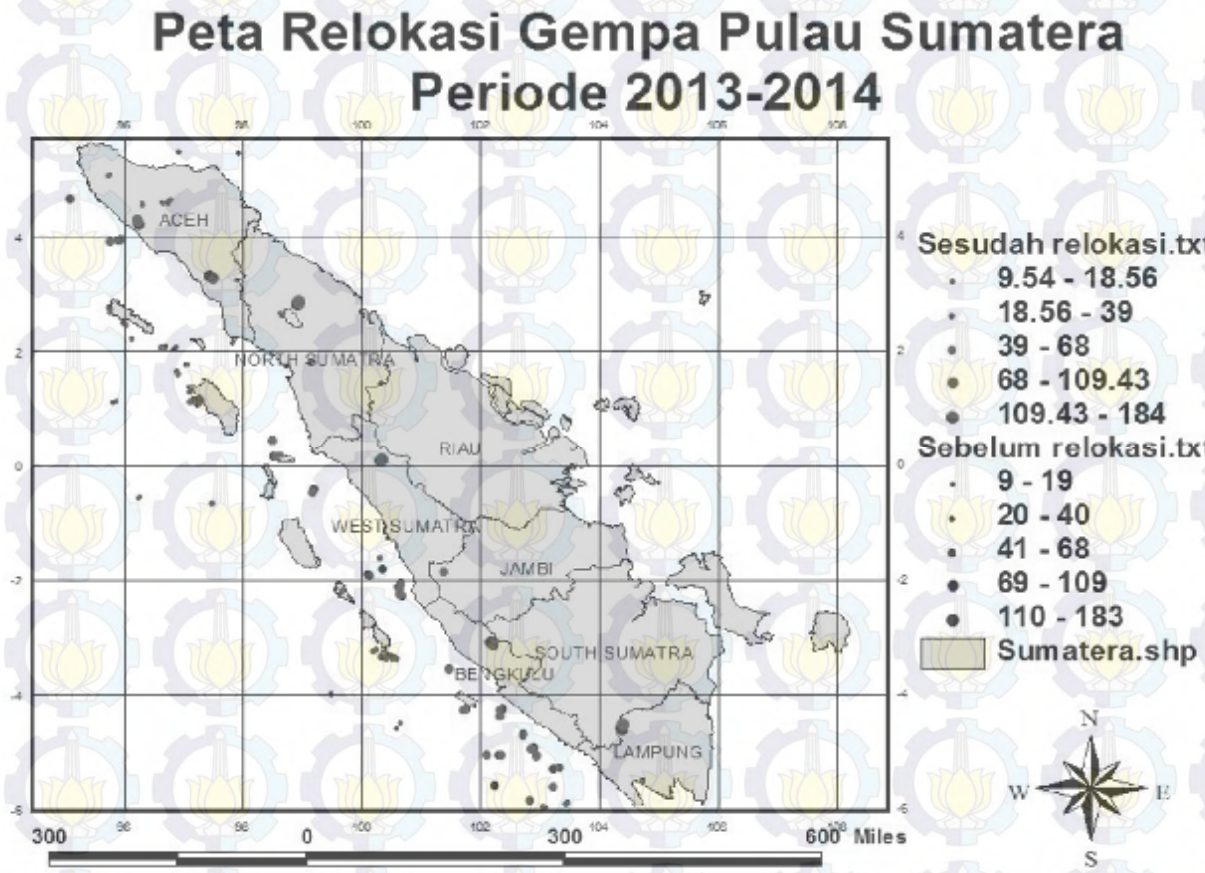
Inversi Tomografi

Model Kecepatan Anomali Gelombang P dan S dalam 3D

Analisis dan Interpretasi

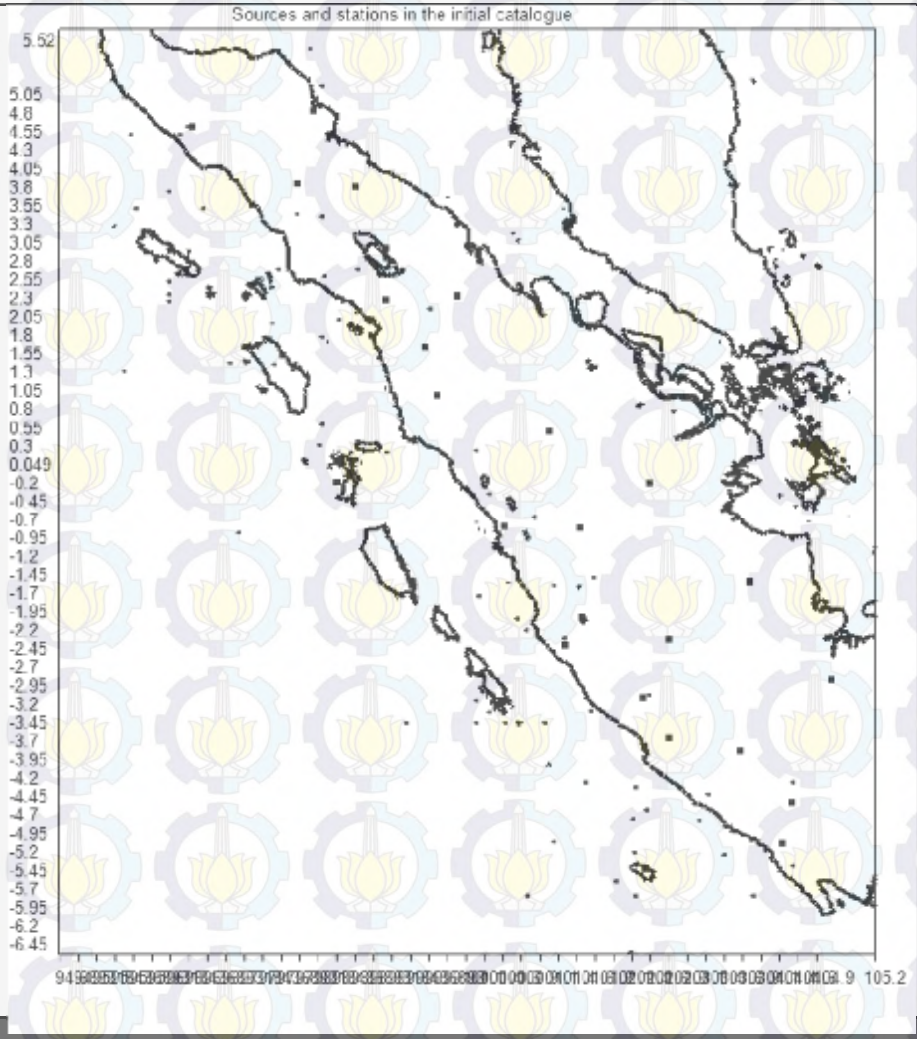
Hasil dan Pembahasan

Posisi gempa sebelum dan sesudah relokasi

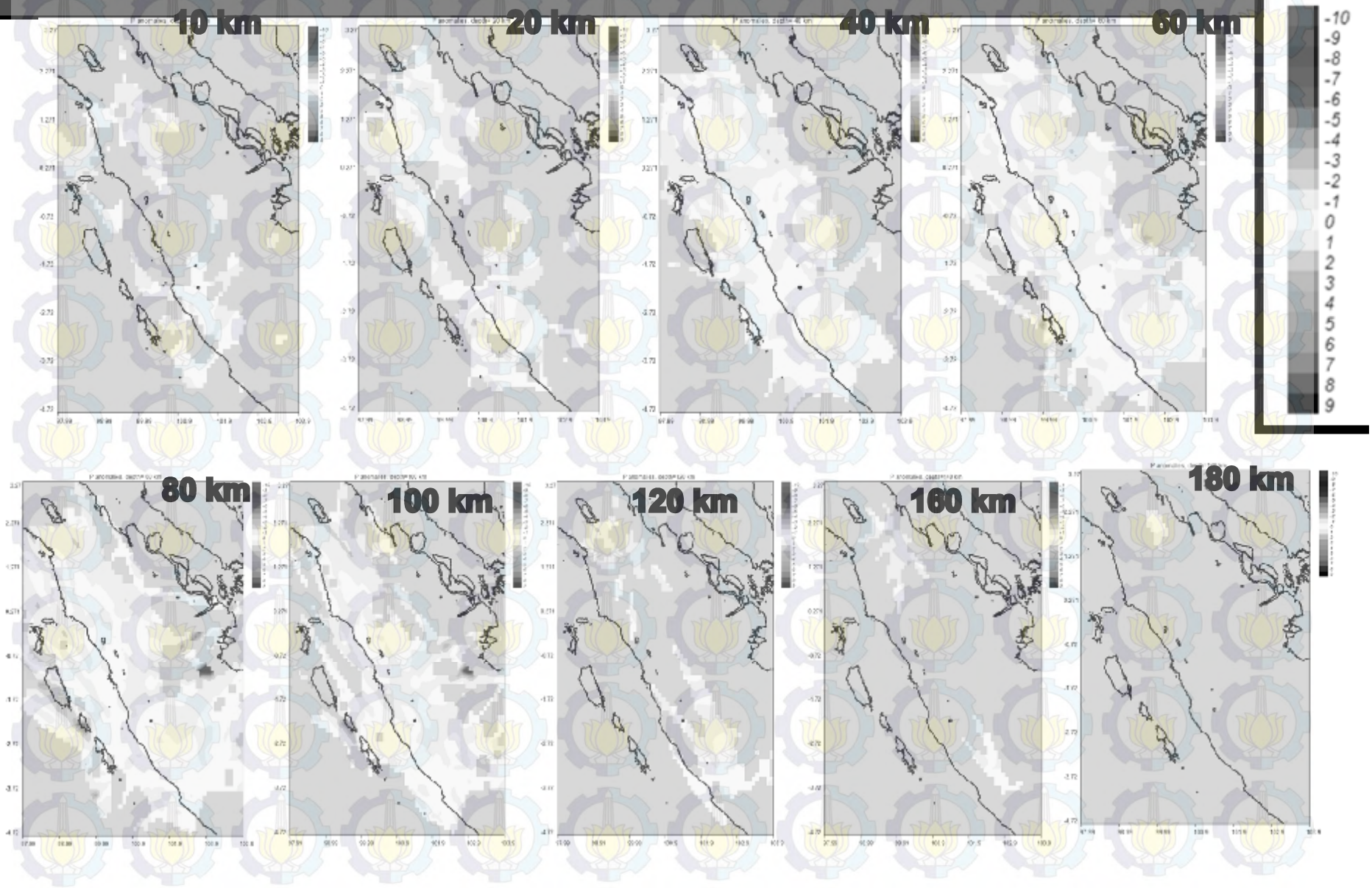


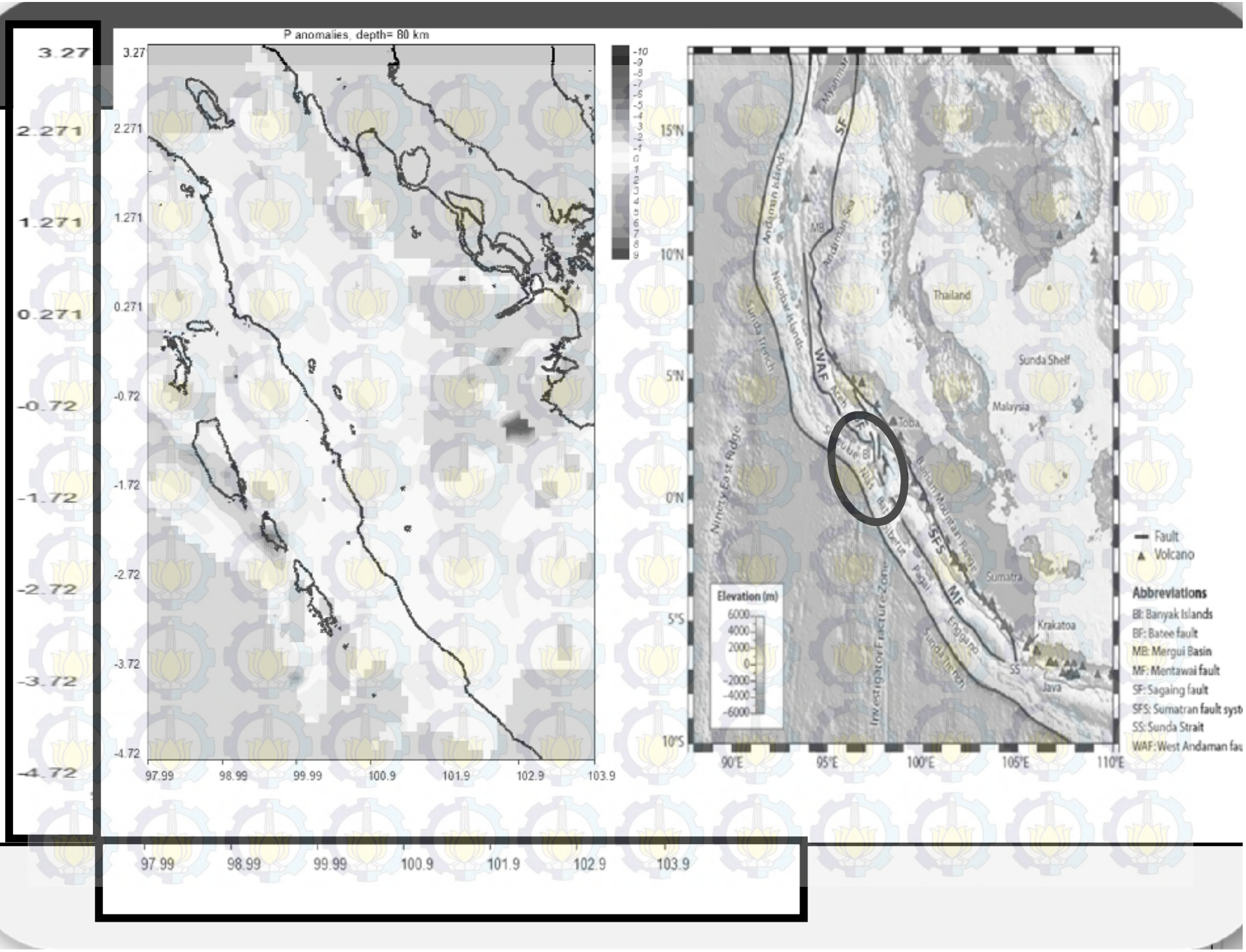
Hasil dan Pembahasan

Persebaran *event* gempa dan stasiun dengan code LOTOS

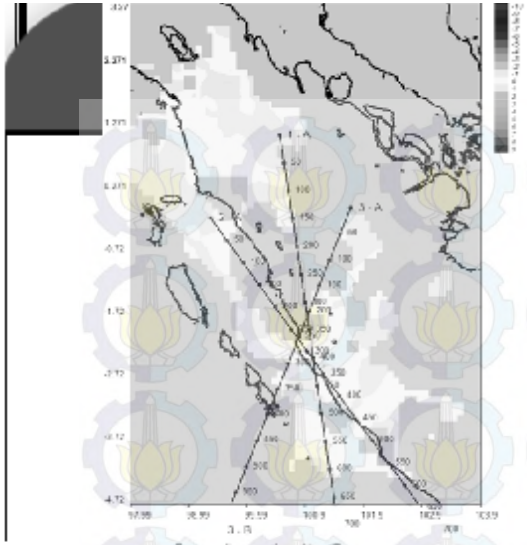


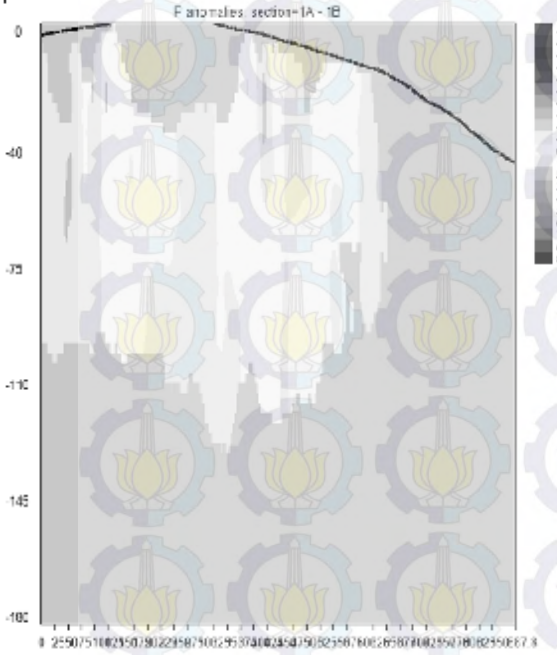
Distribusi anomali Vp sayatan horizontal

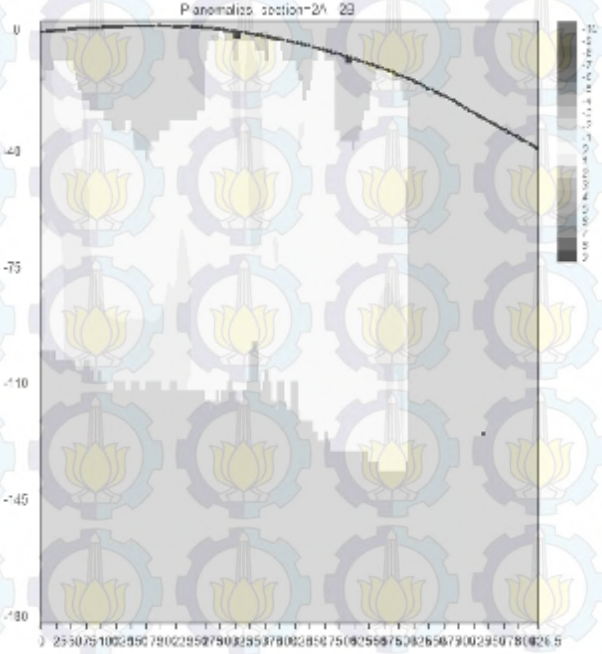


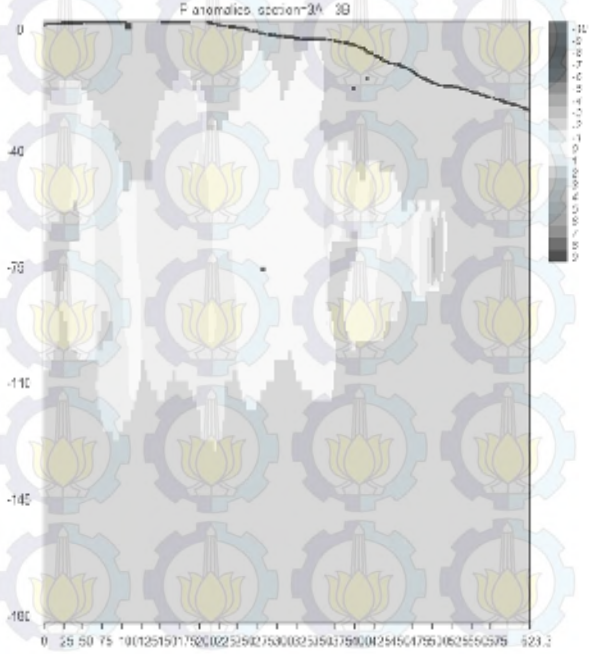

P anomalies, depth= 80 km
3.27
2.271
1.271
0.271
-0.72
-1.72
-2.72
-3.72
-4.72
97.99
98.99
99.99
100.9
101.9
102.9
103.9
15°N
10°N
5°N
0°N
5°S
10°S
90°E
95°E
100°E
105°E
110°E
Myanmar
SF
Andaman Islands
MB
Andaman Sea
Nicobar Islands
Sunda Trench
WAF
Thailand
Sunda Shelf
Malaysia
Toba
Ninety East Ridge
Sumatra
SFS
MF
Krakatoa
SS
Java
Investigator Fracture Zone
Elevation (m)
6000
4000
2000
0
-2000
-4000
-6000
Fault
Volcano
Abbreviations
BI: Banyak Islands
BF: Batee fault
MB: Mergui Basin
MF: Mentawai fault
SF: Sagaing fault
SFS: Sumatran fault syst
SS: Sunda Strait
WAF: West Andaman fau

Cross Section dan Anomali Vp sayatan vertikal

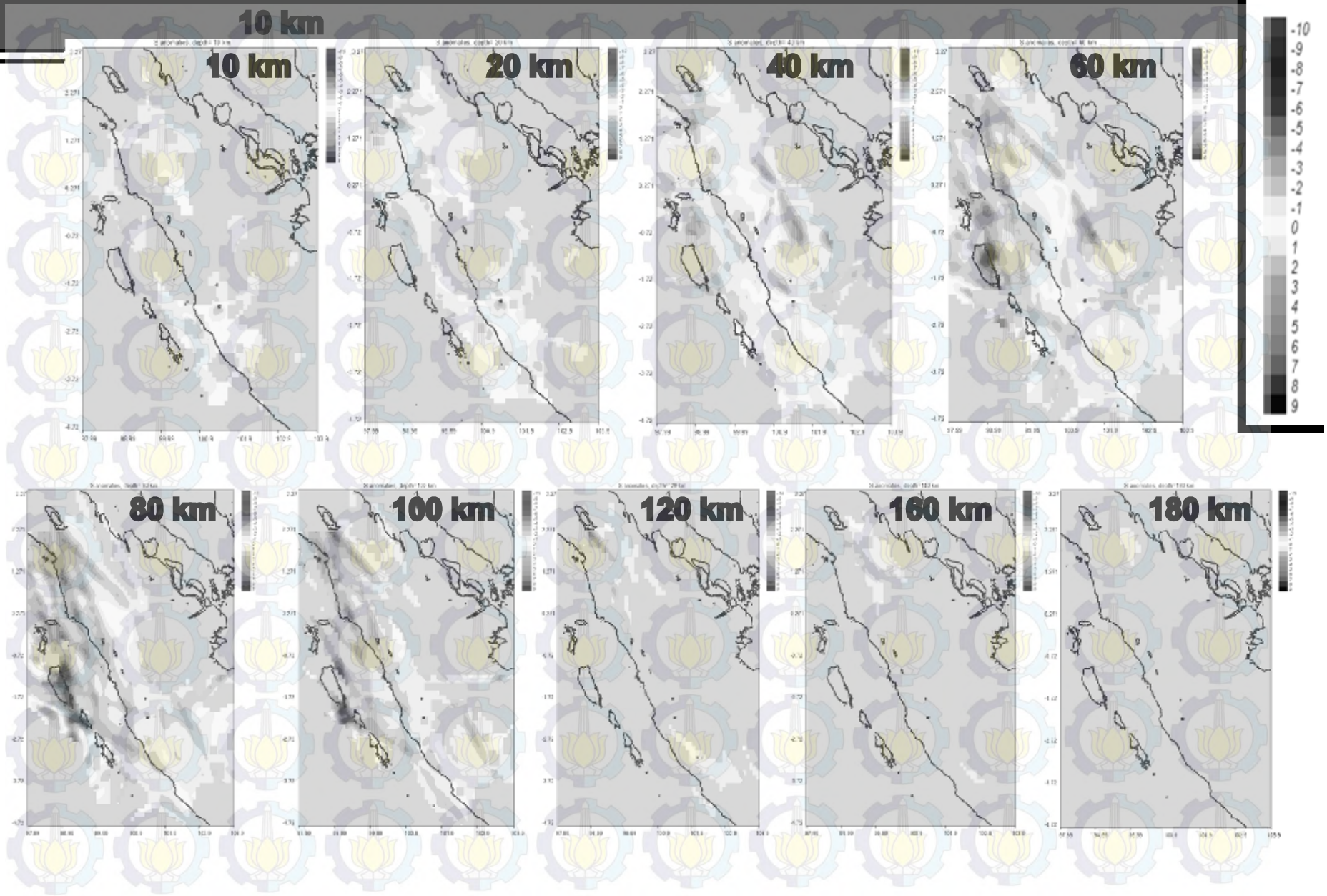


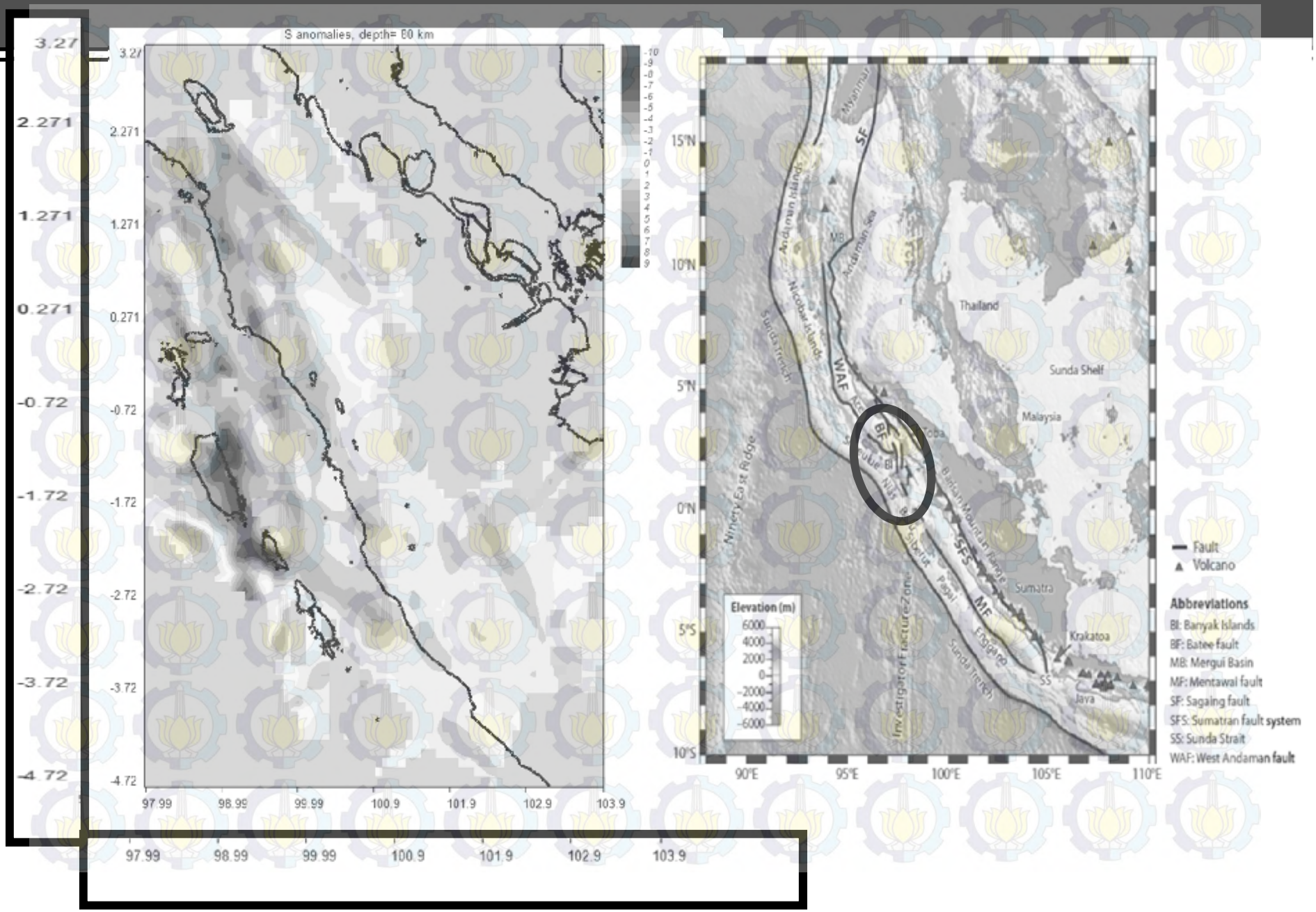






Distribusi anomali Vs pada horizontal




S anomalies, depth= 80 km
3.27
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1.271
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-2.72
-3.72
-4.72
97.99
98.99
99.99
100.9
101.9
102.9
103.9
15°N
10°N
5°N
0°N
5°S
10°S
90°E
95°E
100°E
105°E
110°E
Myanmar
SF
Andaman Islands
MB
Andaman Sea
Nicobar Islands
Sunda Trench
WAF
Thailand
Sunda Shelf
Malaysia
BF
BI
Ninety East Ridge
Barisan Mountain Range
SFS
Sumatra
MF
Investigator Fracture Zone
Sunda Trench
Krakatoa
SS
Java
Elevation (m)
6000
4000
2000
0
-2000
-4000
-6000
Fault
Volcano
Abbreviations
BI: Banyak Islands
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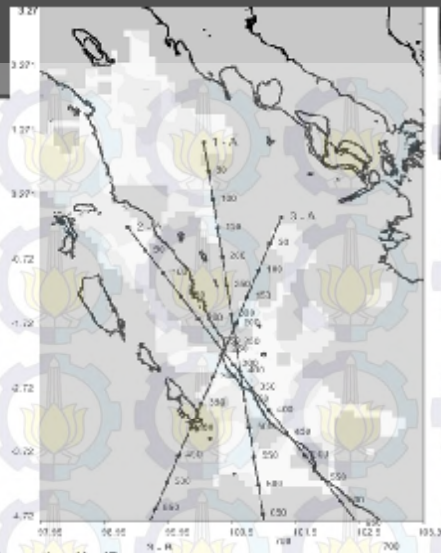
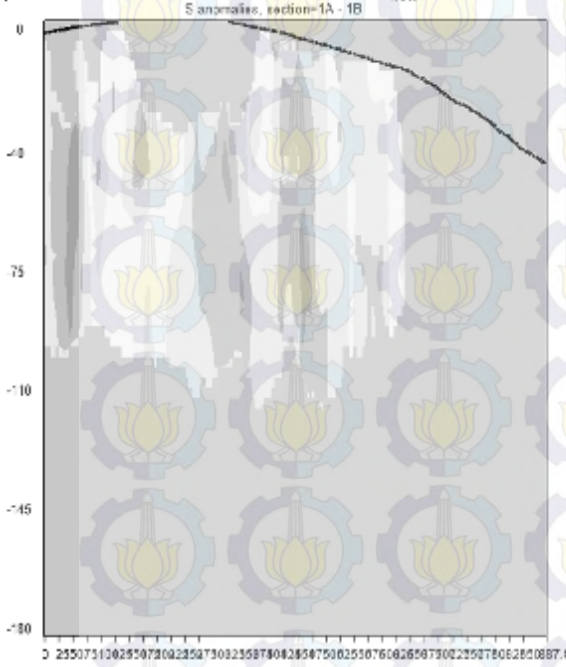
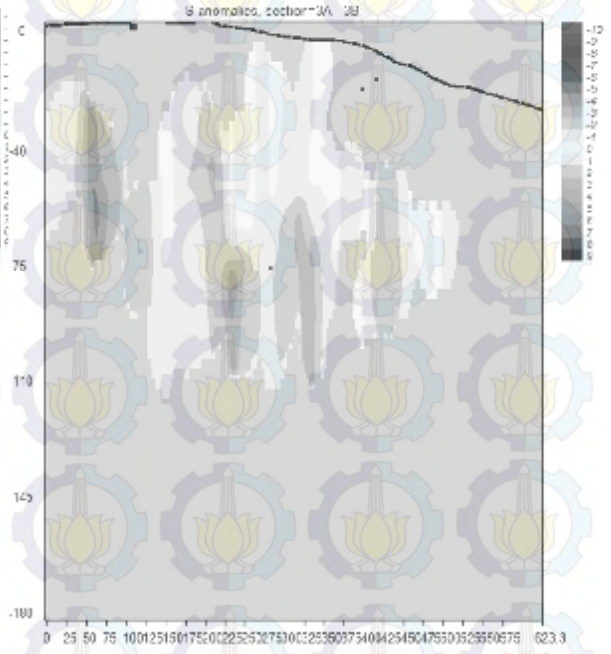
SFS: Sumatran fault system
SS: Sunda Strait
WAF: West Andaman fault

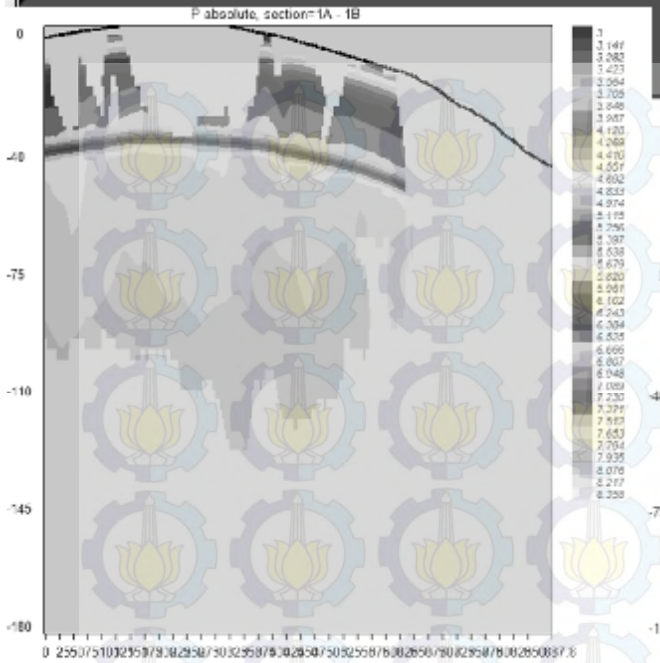
Cross Section dan Anomali Vs sayatan vertikal

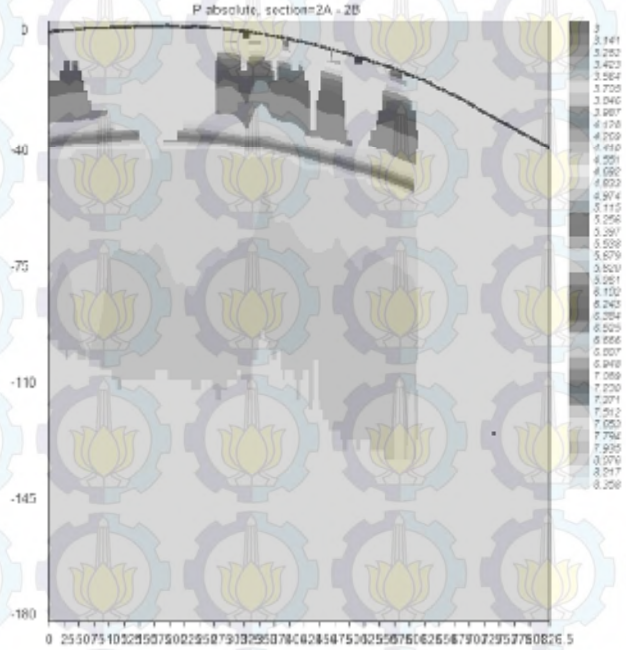


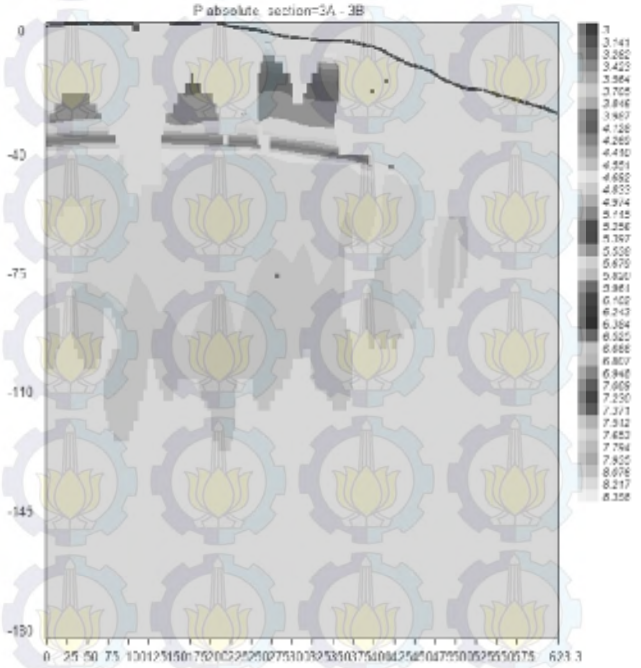




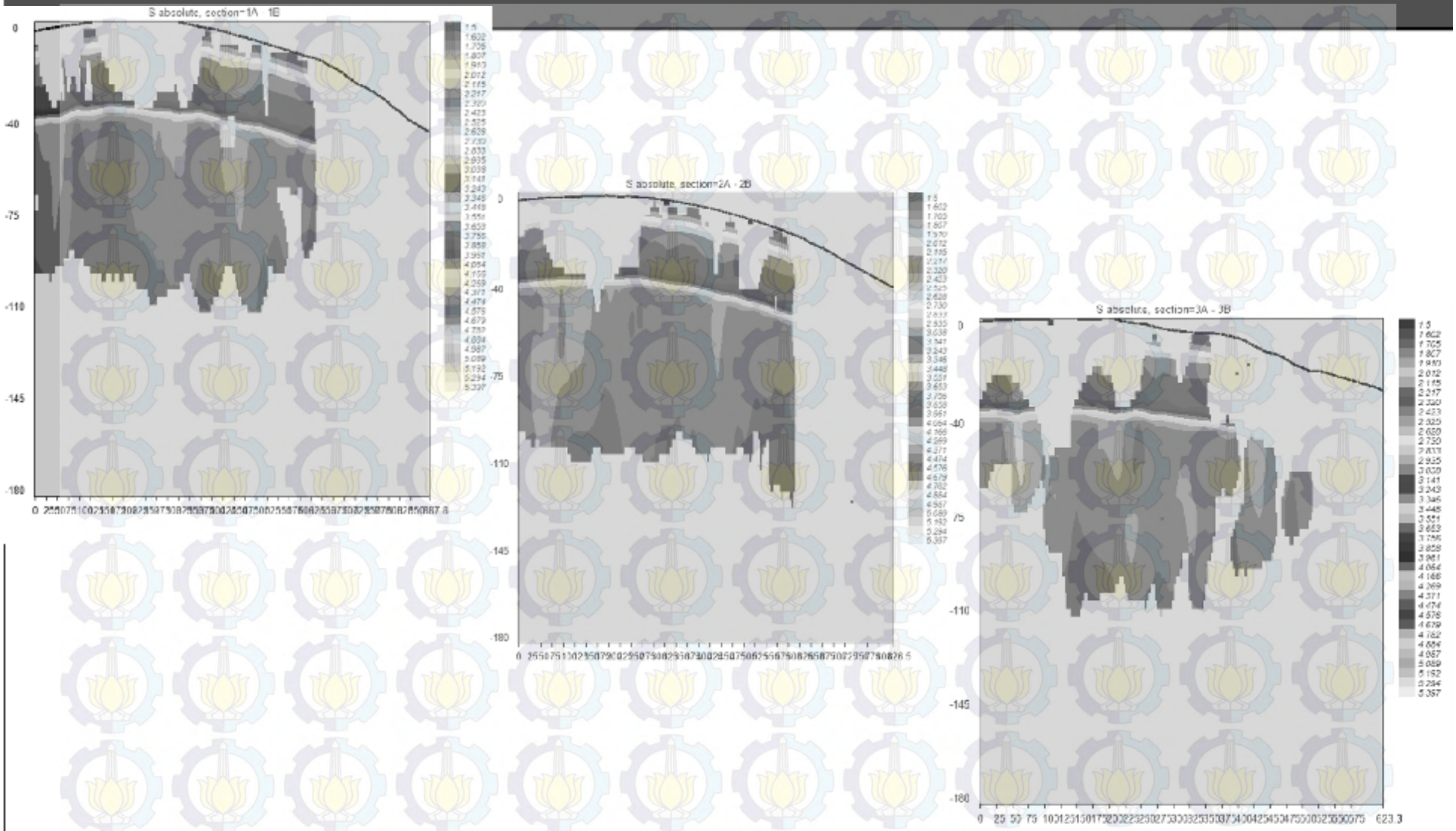
Anomali Vp absolut sayatan vertikal



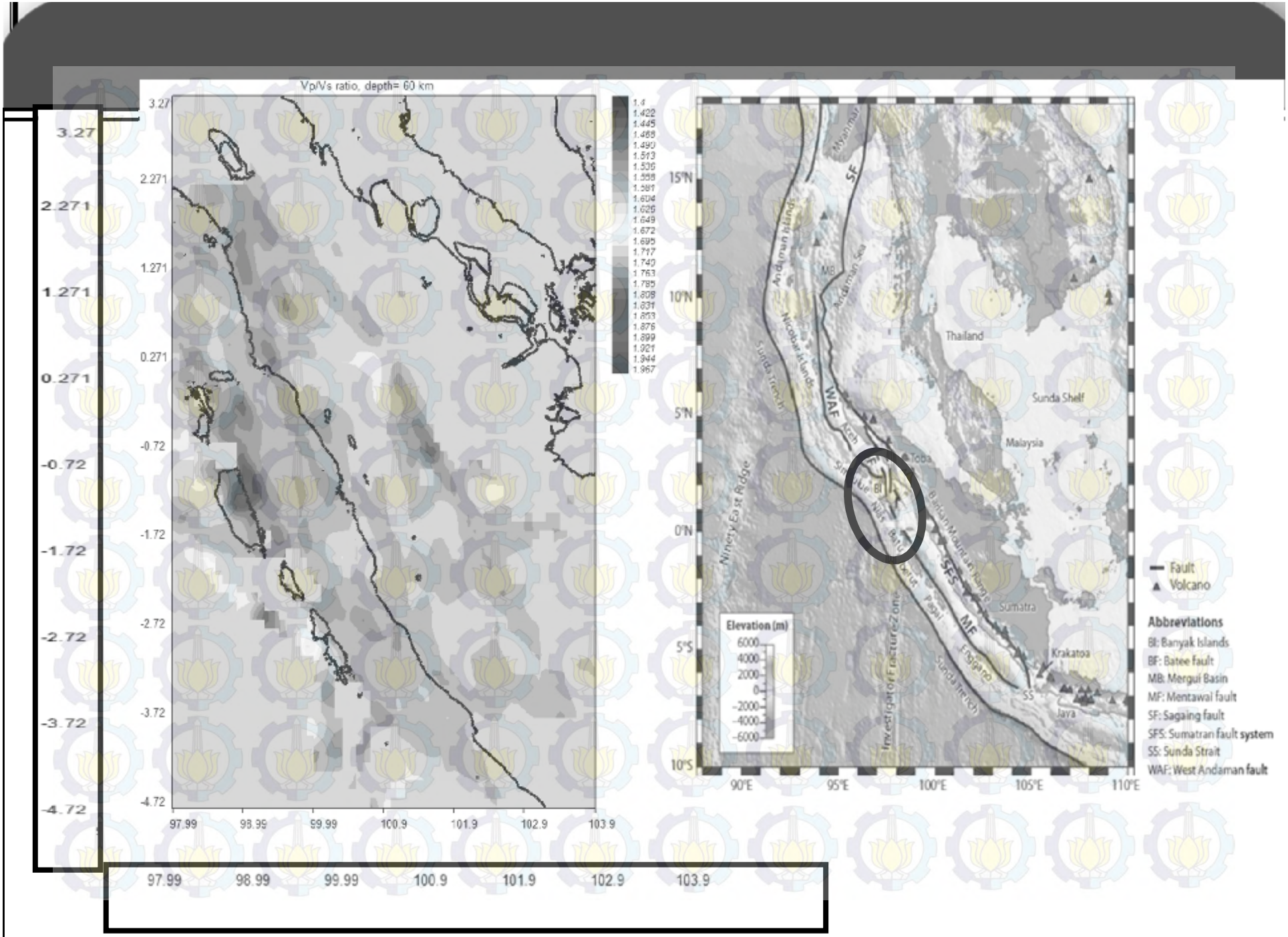




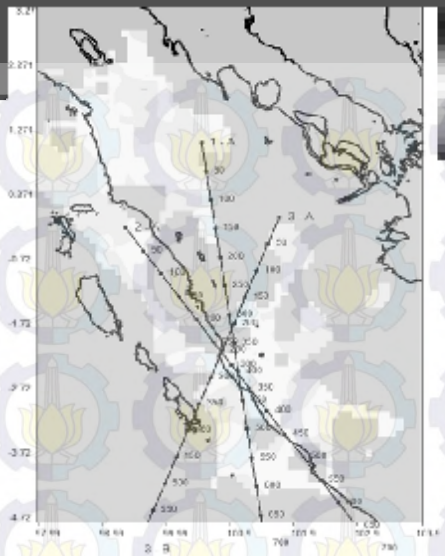
Anomali Vs absolut sayatan vertikal

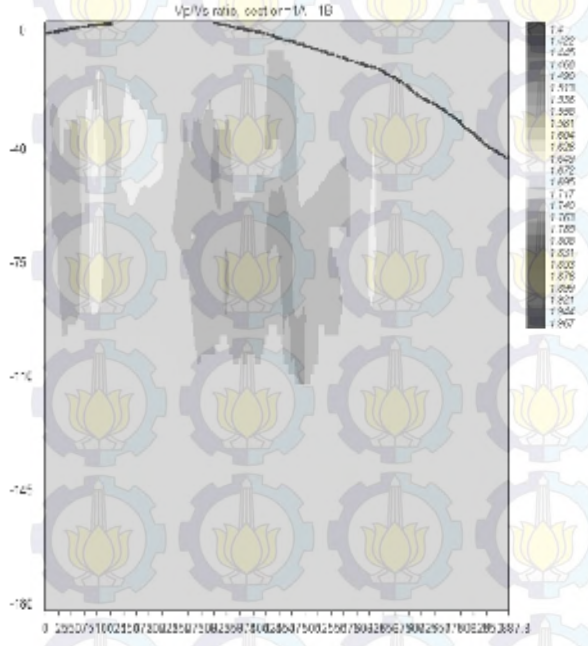


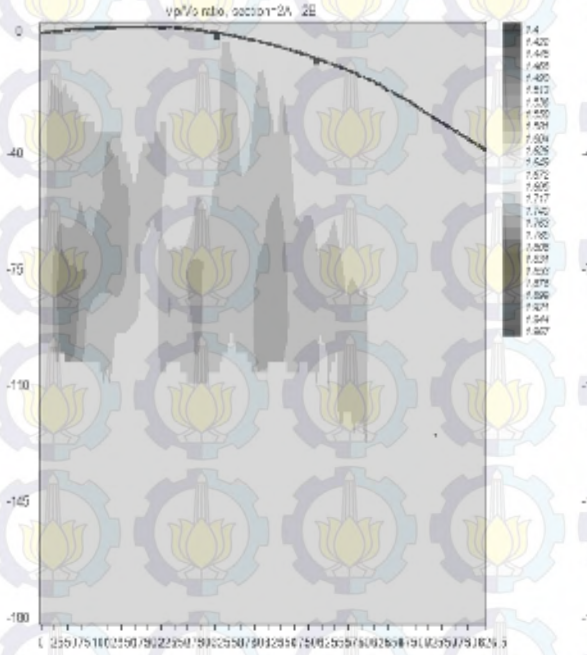
Distribusi anomali Vp/Vs pada horizontal

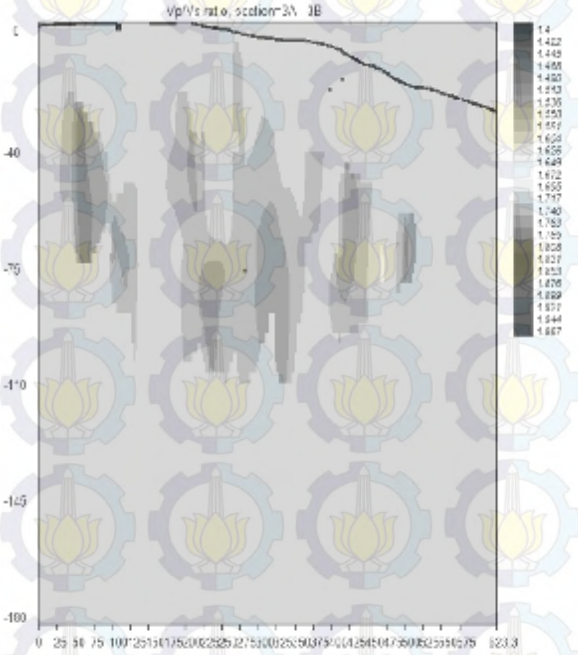

Vp/Vs ratio, depth= 60 km
3.27
2.271
1.271
0.271
-0.72
-1.72
-2.72
-3.72
-4.72
97.99
98.99
99.99
100.9
101.9
102.9
103.9
15°N
10°N
5°N
0°N
5°S
10°S
90°E
95°E
100°E
105°E
110°E
Myanmar
SF
Andaman Islands
MB
Andaman Sea
Nicobar Islands
Sunda trench
WAF
Aceh
Thailand
Sunda Shelf
Malaysia
Toba
BI
Batee
Ninety East Ridge
Barisan Mountain Range
SFS
MF
Sumatra
Padai
Investigator Fracture Zone
Enggano
Sunda trench
Krakatoa
SS
Jaya
Elevation (m)
6000
4000
2000
0
-2000
-4000
-6000
Fault
Volcano
Abbreviations
BI: Banyak Islands
BF: Batee fault
MB: Mergui Basin
MF: Mentawai fault
SF: Sagaing fault
SFS: Sumatran fault system
SS: Sunda Strait
WAF: West Andaman fault

Cross Section dan Anomali Vp/Vs sayatan vertikal









Penutup

Kesimpulan

ü **50 *event***: **P-waves**=621 **S-waves**=578; **koordinat** 95.09 hingga 104.39 dan -5.96 hingga 5.48 di **kedalaman** 9.54 km hingga 184 km.

ü**Kerak atas:** Vp=6.525 km/s, Vs=4.064 km/s; **Kerak bawah:** Vp=7.230 km/s, Vs =4.269 km/s; **Mantel atas:** Vp=7.935 km/s, Vs 4.679 km/s.

ü Rasio Vp/Vs **Minimum**=1.695 dan **Maksimum**=1.899.

ü**Bidang Vertikal** rasio Vp/Vs rendah diperoleh mayoritas di kedalaman sekitar **0-55 km**, sedangkan rasio Vp/Vs tinggi di kedalaman **55 km-110 km**.

ü**Anomali negatif** di daerah **kepulauan Mentawai dan Nias**, dikarenakan pada daerah tersebut terdapat beberapa jenis patahan: **patahan Andaman, patahan Batee dan patahan Mentawai.**

Saran

Perlu adanya penambahan jumlah data gempa yang mempunyai distribusi sinar yang merata untuk mendapatkan citra tomografi yang lebih real dan dilakukan pengujian dengan data sintesis.

TERIMA KASIH

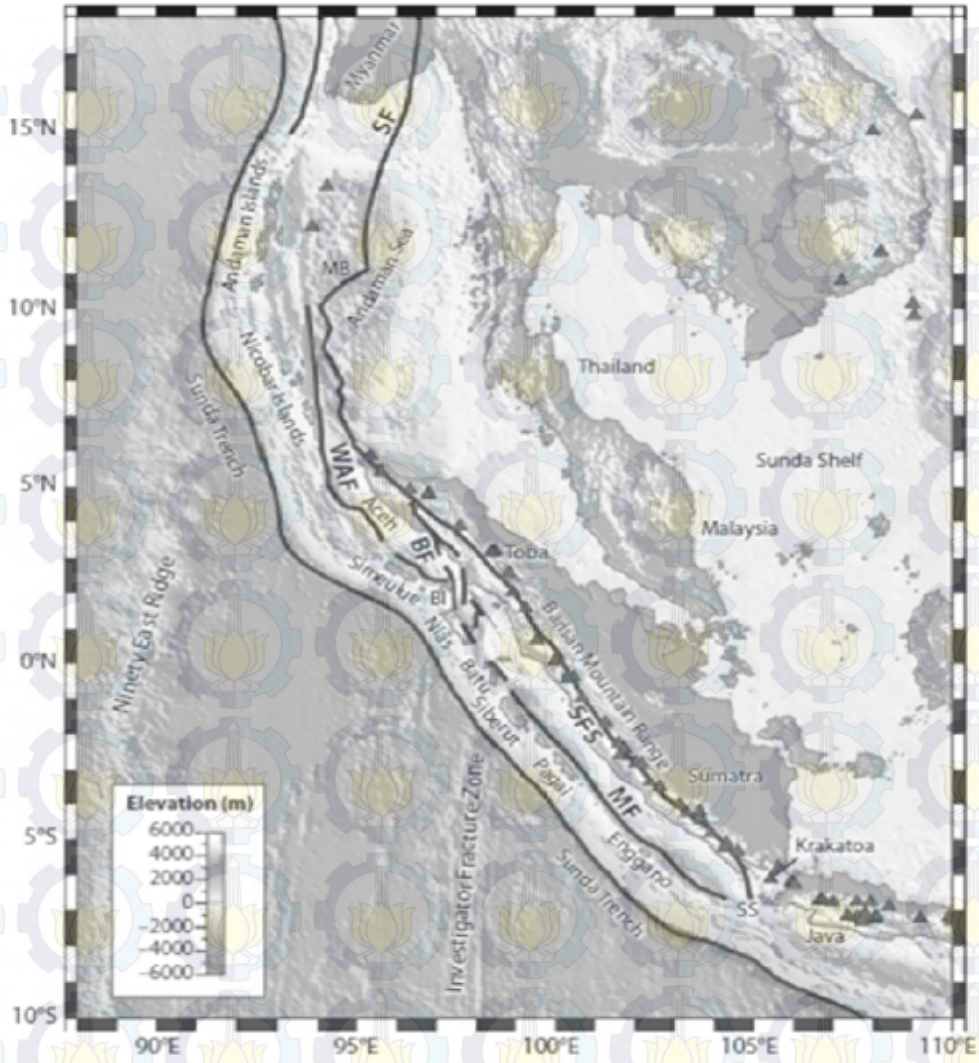
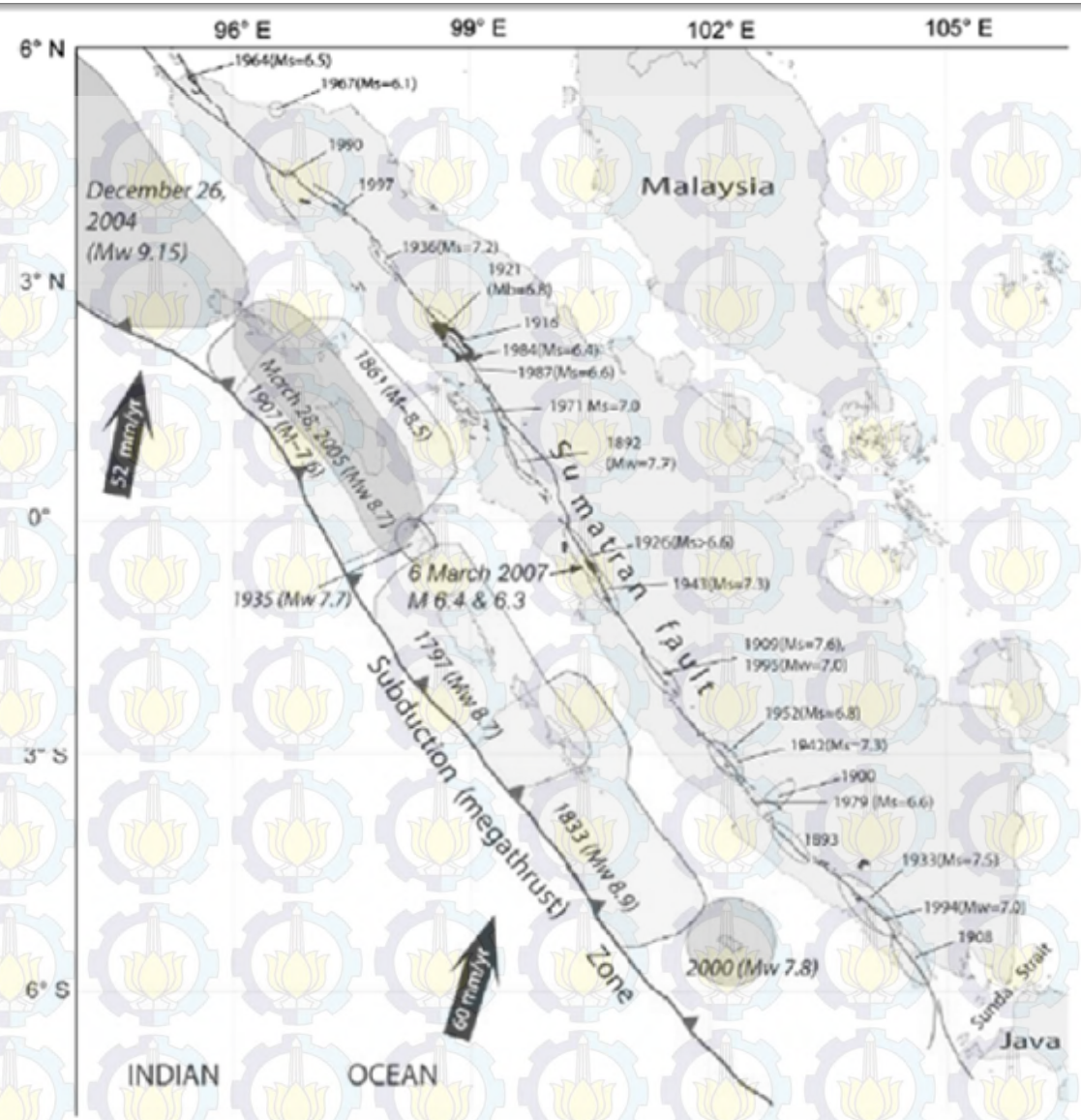


Figure 2

Physiographic map of the Sumatran region. The triangles are locations of active volcanoes. The thick red lines are faults. Data from the Global Volcanism Program, **www.volcano.si.edu.**



Gambar III-10 Gempa-gempa historis yang pernah terjadi di wilayah Sumatera (*Natawidjaja dkk., 2007*)

BACK

Penelitian terdahulu

-Puspito et al (1993): struktur Vp 3D wilayah Indonesia dengan metode ARTB, optimasi Bayesian

-Widiyantoro dan Van der Hilts (1997): struktur mantel bumi indonesia dengan tomografi tinggi

-Widiyantoro dan Puspito (1998): Penunjaman di bawah sumatera memiliki slab yang terputus

-Pesicek et al (2008): subduksi slab di sumatera

-Caffrey (2009): tatanan tektonik & zona subduksi di sumatera

-Handayani (2012): segmentasi tektonik aktif pulau sumatera

Penelitian Vp & Vs di Sumatera

Ardianti (2012), studi spesifik Vp Vs Sumatera Barat

Parameter	Nilai rata-rata	Kedalaman
Vp in conrad	6.120-6.987 km/s	19.650 km
Vs in conrad	3.535-4.007 km/s	19.650 km
Vp in Moho	6.987-4.787 km/s	45.030 km
Vs in Moho	4.007-4.737 km/s	45.030 km
Vp/Vs	1.375km/s	

Sudiyanto (2014), studi spesifik Vp Vs Bengkulu

Parameter	Nilai rata-rata
Vp sebelah utara Gunung Dempo	Sekitar 7.35 km/s
Vp sebelah utara gunung Bukit Daun	Sekitar 7.71 km/s
Vs sebelah utara Gunung Dempo	Sekitar 4.19 km/s
Vs sebelah utara gunung Bukit Daun	Sekitar 4.28 km/s

Contoh kelurusan seismogram